Design of Acoustic Sources for Use with the Acoustic Observatory Receiving Array

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LONG-TERM GOAL

The long term goal is to design and construct a very low frequency source array for the proposed Acoustic Observatory (AO) in the South Florida Testing Facility range off Dania Beach, Florida to support both applied and basic research in shallow underwater acoustics.

OBJECTIVES

Once the observatory receiving arrays are in place experimental research can commence. There are both applied and basic research objectives. Source requirement for both objectives were the concern of this study. The applied research is focused on establishing the limits of passive sonar. Acoustic sources should simulate submarine signals with content of line signals, i.e. CW wave forms, as the detectable signal in a background of shipping noise which has similar spectral content. Signals from both fixed and moving sources should be used since differential Doppler can limit the coherence length of arrays. The basic research program that will use AO assets has yet to be decided. The objectives differ. Understanding the effects of the ocean environment on shallow water propagation is the central goal. However, the result will be of practical importance in extrapolating the AO passive study conclusions to other shallow ocean areas.

APPROACH

Basic research sources and transmitted signals must facilitate the observation channel pulse responses (CPR) and require broadband signals typically with a Q=4. The CPR is a fundamental tool for analysis that resolves arrivals patterns. Identifying arrivals with propagation models determines the ray/mode path structure through the ocean is the first analytical step in determining the effects bottom interactions and fluctuations from sound speed variability. An alternative to CPR measurement is the use of a vertical line array of sources to insonify individual modes/rays and thereby study arrival patterns. Such a VLA need not be broadband.

Here a number of approaches are considered and weight with the design criterion of cost, frequency, bandwidth, efficiency and environmental concerns. A specific task requested at the beginning on the study was to consider the design of a very low frequency (25 - 100 Hz) vertical line array. The selection of a basic research source configuration was not specified or suggested but turns out to be the major effort.

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14. ABSTRACT
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WORK COMPLETED

At the beginning of this study selection of sources for the applied main AO effort was undecided. One approach under consideration was a 25 to 100 Hz. vertical line array. Such a design is inherently difficult and costly. Generally, low- frequency transducers are inefficient, difficult to power. The power requirement prohibit battery powered autonomous systems and thus ship board generators and suspended sources are the rule.

The application of very low frequency sources transmission has lead to important breakthroughs in understanding for deep ocean propagation. However, shallow water channel do not carry low frequency sounds well. Many studies have shown that both high and low frequencies attenuate in shallow water. High frequencies are absorbed in the bottom and low frequency modes do not fit into the channel dimensions and leak into the bottom. Generally, channels deep enough to allow submarine operation have optimal (lowest loss) transmission at around 400 Hz.

There are a limited number of options for very low sound generation. Hydro-acoustic broadband sources have been used with success and have the low frequency capability but have very low efficiency and require excessive power for the moored application – generally 230 volts 3 phase and 40kva!. There are also heavy (tons) and a vertical line array of such sources, even if powered from shore would be impractical.

One novel approach considered here attempts to improve efficiency by design of very narrow band and highly resonant sources. The design proposed here consists of a gas-filled rubber diaphragm driven by a moving coil projector (C.C. Sims, Bubble Transducer for Radiating High-Power Low-Frequency Sound in Water, J. Acoust. Soc. Am., Vol 32, No. 10 1305-1308). An alternative configuration that may present a significant cost advantage uses a gas-filled rubber diaphragm driven by a piezoelectric circular disc projector. This type of projector would have fractional Hz bandwidth when implemented at 25 Hz and the gas control system would be servo-controlled to align the resonance frequency of the bubble to that of the control signal. The electronics required to perform this control depth compensation and the resonance frequency control function can be implemented with simple control circuitry located with the gas system. Electro-acoustic efficiency would be at least 15% and source levels to 160 dB would be achieved. The funding requested is for a single prototype 25 Hz source at cost of $50k. Once the source is developed and the concept is proven the price to manufacture this type of projector is estimated in the $20K region. Six of these units could be moored in a phased array to produce discrete tonal with 175 dB source level at a single frequency as low as 25 Hz. Questions about the frequency and phasing for the array application would require analysis and experiment with the prototype. We believe this to be a feasible and practical design but one limited to a single frequency. Indeed, power requirements are modest and a moored design seems practical.

As the study period advanced, the AO planning decided to use and obtained on loan an existing HLA low frequency source package. The plan is to suspend the source from a moored barge that will contain driver electronics and power supplies. The barge will be moored at different locations from the receiver. This plan is adequate for the applied objectives of the AO program and squelched the impetus for the study reported here. Emphasis shifted towards sources for more general scientific research.

A general purpose source for exploratory research should support broad band transmission to resolve arrival patterns and have sufficient power to give high signal to noise at receiver so that statistics of signal fluctuations will be uncontaminated by noise.

Through the years, beginning with the MIMI experiments in the Florida Straits, circa1965, the fundamental idea of M-sequences (Ted Birdsall, 1962) have evolved to be in general use by most on the basic research community. Sources and receivers that can operate under battery power for periods of months at sea with m-sequence transmission and reception have evolved. With one exception, sources in use today were developed in support of the Tomography studies. They are mostly organ pipe design of Doug Webb and are typically 220 Hz center frequency with a 10 t0 15% bandwidth. Most of these sources have reached there useful lifetime and little investment has been made to refurbish or improve these devises over the past twenty years.

The one exception is the "Miami Sound Machine" (MSM) a one of a kind multi-frequency source that was developed in support of the Surface Reverberation SRP circa 1995. The source is unique in that it covers frequency range from below 100 Hz. to 3200 Hz. with six sets of transducers that transmit a center frequencies of 100,200,400,800 1600 and 3200 Hz. However for the AO experiments the high frequency transducers need not be used. Further, the source has been successfully used in basic research experiments in the Florida Straits very near planned site of Acoustic Observatory arrays. Issues of environmental compliance about the effect of low-frequency sound on marine mammals have been resolved. A "FONSI" (Finding of No Significant Impact) has been issued for this source in the Florida Straits thus avoiding a potential stumbling block of environmental permitting.

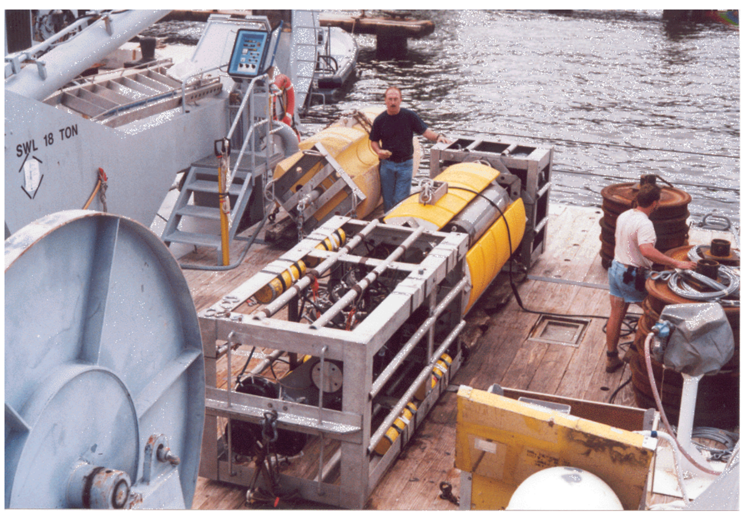

Figure 1 Miami Sound Machine

Fc = 100,200,400,800,1600,3200. Hz.
Bw= 25 , 50, 100,200, 400, 800.

The MSM is shown in figure 1. The transducers are air-backed and pressure compensated with an active regulator and compressed air supply. Four transducers compose the 100 Hz. set and they are positioned at the bottom of the package with floatation and batteries in the mid section and the remaining transducers at the top. Each of the four transducers has a slightly different frequency and a narrow band but in combination a 25 Hz band width centered at 100 Hz is achieved. Likewise there are 3 transducers for the 200, 400 and 800 Hz bands and a single transducer for the 1600 and 3200 Hz. The net result is a 25% of center frequency at each of six center frequencies 100,200,400,800,1600 and 3200 Hz. However for the AO application the source will be reconfigured with the lower frequency.

The source level, verified by calibration, is 198 dB//up for all frequencies. However, environmental concerns limit the field levels to 186 dB for extended periods- days but higher for shorter transmissions. The efficiency approaches 44% which allows for continuous duty cycle for 28 days. The key to the high efficiency is the air-backed pressure compensated design.

RESULTS

Broadband sources and M-sequences signals allows separation of arrivals and, with the help of propagation models, mode and ray types can be identified and isolated for study by simple time gating. In this way analysis of bottom interaction and the effects of sound speed variability is greatly simplified.

The Miami Sound Machine, described herein is a-one-of-a-kind resource that has:

- Frequency range of interest for AO research.
- A history of reliable performance at sea for periods of months under battery power.
- Environmental permits in place.
- Demonstrated coherent pulse response signal processing over vertical and horizontal arrays of nearly the same lengths as those planned for the AO.
- Mature and tested software for signal processing and propagation model predictions comparisons.
- Signal processing algorithms for the simultaneous measure of signal and noise over the same band.

IMPACT/APPLICATIONS

The ocean-acoustic environment at the planned site of the AO is highly variable. Results of previous experiments have established the influence of mesoscale eddies to completely alter the acoustic modes of transmission over a matter of several minutes. Further, the intrusion of eddies on to the shelf area of the acoustic observations develops a duct for seaward internal waves to propagate through the sound path. By this mechanism the potential energy of the internal wave field has been observed to increase by one or two orders of magnitude over the period of a day.

A continuous background experiment, using the MSM, is recommended. Direct observation acoustic propagation effects at the site will greatly simplify interpreting and understanding the results of the AO adaptive processing.

RELATED PROJECTS

Two 1-month long experiments in the Florida Straits were conducted, one with the source at a range of 10 km and the other, a year later, at a range of 20 km. The site location is in close proximity to the AO array location. The experiments were designed to resolve arrivals and to study fluctuations, coherence, and predictability in a parameter space of frequency, range, and experimental geometry. Briefly, the multi-frequency broadband source was moored at a range of 10 km from a vertical and two horizontal arrays that were connected to shore by fiber-optic cables. The source transmitted pulses with center frequencies of 100 200, 400, 800, 1600, and 3200 Hz. In each case, the bandwidth of the pulse was 25% of the center frequency (q=4). Environmental moorings measured temperature and conductivity at 10 depths and at two locations along the range. Range dependence of c(z) and bathymetry were minimized by transmitting parallel to shore along a nearly constant depth contour.

The sequence of events for the propagation experiments was a 6-hour long transmission set that was repeated for 28 days. The first hour consisted of pulse-like transmissions with a center frequency of 100 Hz, then an hour of 200 Hz, then 400Hz, and so on, ending with the 3200 Hz. signal. In each case, a continuous m-sequence with a repetition period of about 2.55 sec modulated the phase of a 4-cycle pulse of the center frequency. The received signals were coherently averaged for 1 minute and the m-sequence pulse compression was applied using SHARP processing (Birdsall, 2000). After processing, the m-sequences are transparent and the resulting pulse responses are the same as if a simple pulse were transmitted and received except for the gain of coherent averaging and pulse compression. (41dB for the 800 Hz. signals). The results of a single transmission set are shown in Fig.3. Each plot contains 58, one minute of coherent averaged pulse responses. A minute is lost in changing frequencies and process bookkeeping at the beginning and end of the hour. The arrival time is relative, that is, reduced by subtracting the mean travel time, which is not observable. Relative arrival times between transmissions are exact.

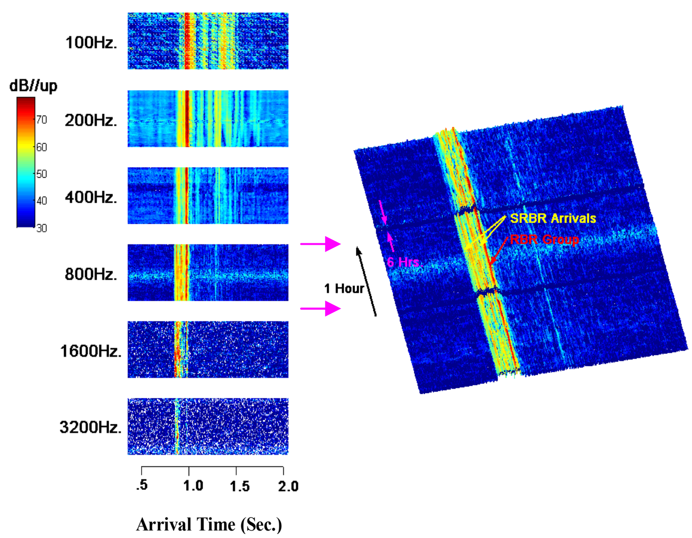

Figure 3. Pulse responses from the Florida Straits

The ability to resolve and identify arrivals is important to understanding and interpreting findings of the AO. Only the SRBR modes carry surface ship noise, while deep sources (submarines) insonify both SRBR and RBR paths. Clearly, transmission loss is much less for the RBR paths. The occurrence of strong downward refracting profile will increase S/N by as much as 10 to 20 dB – an effect that must be accounted for to make sense of AO processing.